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The Demand for Crop Genetic Resources: International Use of the US National Plant Germplasm System

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Summary. — In contrast to a perception that *ex situ* collections of germplasm are rarely used, this empirical case study reveals large numbers of germplasm samples distributed by the US National Germplasm System to many types of scientific institutions located in numerous countries around the world. Germplasm distributions outside the United States favor developing over developed countries in several ways, including the numbers of samples shipped, utilization rates in crop breeding programs, and the secondary benefits brought about through sharing this germplasm with other scientists. Expected future demand is also greater among scientists in developing countries. These findings underscore the importance to global science and technology of retaining such resources in the public domain.

Key words — developing countries, crop genetic resources, plant breeding, germplasm collection

1. THE GLOBAL ROLE OF GERMPLASM COLLECTIONS

Regardless of where they live, the world's farmers face rising expectations concerning either the quantity or the quality of the food they produce. The expected growth in world population will increase food demand, with much of the increase coming in areas already without fully adequate food supplies. In many parts of the world, farmers continue to cope with difficult production conditions and have few alternative sources of income to purchase food when their crops fail. In richer countries, producing sufficient quantities of food is hardly an issue, though as their incomes rise, consumers demand enhanced environmental amenities, such as decreased use of toxic agricultural chemicals, or unique product attributes. In the meantime, physical constraints, such as land quality or water availability, limit the expansion of agricultural land in both developed and developing countries. Plant breeding can help meet these challenges by adding traits that enhance quality, improve tolerance to climatic conditions, or provide disease resistance that is based on combinations of genes rather than purchased chemical inputs.

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Crop improvement through plant breeding critically depends on crop genetic resources. All crop output, whether it is the harvest of traditional varieties selected by farmers or modern varieties bred by professional plant breeders, is in some way descended from an array of wild and improved genetic resources from around the world. Advances in yield potential, resistance to pests, quality, or other desirable traits in modern varieties have resulted from the crossing of diverse parental material by professional breeders. Both farmers who consume their crop output and professional plant breeders depend on crop genetic resources; in turn, farmers' selection efforts and the achievements of modern plant breeders have generated other genetic resources.

Plant breeding issues are not resolved once and for all—they persist because the problems of crop production change. Pests, pathogens and climates evolve and change, so that breeders continually need new genetic resources from outside the stocks they work with on a routine basis (Duvick, 1986). The US Department of Agriculture estimated that new varieties are resistant to biological stresses for an average of 5 years, while it generally takes 8–11 years to breed new varieties (USDA, 1990). Plant breeding can take longer in the developing world, depending on the crop and resources available to the breeder. In disease hotspots, such as those for the rusts of wheat in the Asian subcontinent or northern Mexico, virulent new strains may overcome genetic resistance based on single genes in only 2–3 years unless more complex mechanisms of resistance are found (Dubin & Torres, 1981; Nagarajan & Joshi, 1985).

Uncertainty about the resources that will actually be needed for improving future agricultural production motivates genetic resource managers, particularly those in the public sector, to collect and accumulate a broad range of germplasm in *ex situ* collections. Funds are limited for genetic resource management, however. Duvick (1995, p. 36) stated that "For thirty years and more, germplasm banks have been in operation… Without exception, and differing only in degree, the collections have been imperiled from the day of their assembly." The economic justification for investing in collections of crop genetic resources has remained a subject of controversy. The perception remains that germplasm collections are underutilized and are of questionable economic value (Simpson & Sedjo, 1998; Wright, 1997).

To address this perception, we offer a summary of how one national genebank is used internationally, based on quantitative data and a study of germplasm requestors. Data reveal large numbers of germplasm samples distributed by the US National Plant Germplasm System (US NPGS) to many types of institutions located in numerous countries around the world. Moreover, rates of utilization are likely underestimated given the long-term nature of scientific research. Germplasm distributions outside the United States favor developing countries over developed countries in several ways. These findings raise questions about previous assumptions concerning the demand for such resources, and may have relevance for ongoing negotiations of international agreements, such as the International Treaty on Plant Genetic Resources for Food and Agriculture.

2. THE US NATIONAL GERMPLASM COLLECTION

The US NPGS provides an interesting point of departure for the study of germplasm collections because of its size, the sheer volume of material it distributes, and the documentation maintained by curators. Many national collections, especially those found in the developing world, do not possess the resources to digitize information regarding their activities. Investments would need to be made to enable them to track requests and distributions of their materials. But when funding is severely curtailed, as it is for many collections, documentation systems are not a priority. In terms of size, US NPGS holdings exceed 450,000 accessions [1] comprised of 10,000 species of the 85 most commonly grown crops, making it the largest national genebank in the world. US NPGS's materials are not held in one location; rather the system consists of a number of publicly funded collections located across the country as well as centralized facilities for coordination, quarantine, and long-term seed storage. Collections include seed and genetic stocks, as well as repositories of clonal germplasm and plant introduction stations.

The US NPGS has a clear mandate to serve the needs of national scientists, and for the 10 major crops we study here (barley, bean, cotton, maize, potato, rice, sorghum, soybean, squash, wheat), about three-quarters of the 621,238 samples shipped over the past decade were destined for US requestors. Nevertheless, the collection is of global importance, as indicated by the amount of germplasm it distributes internationally. For these 10 crops only, during the past decade the US NPGS distributed 162,673 germplasm samples to scientists in 191 countries and 45 territories, departments, or commonwealth associations outside the United States (Appendix). All available germplasm from the US NPGS is provided to anyone free of charge, upon request, though special permission is required to fill germplasm requests from countries with which the United States does not maintain diplomatic relations.

A comparison with the volume of distributions from other genebanks is illustrative of the international role of the US NPGS. All economically important crops have gene bank collections, and there are hundreds of such collections worldwide, with roughly six million accessions for all crops (FAO, 1998). The Consultative Group on International Agricultural Research (CGIAR) research centers hold substantial proportions of the accessions included in these collections. One of these centers, the International Center for Maize and Wheat Improvement, distributed 20,540 samples of maize and 39,770 samples of wheat to from 1987 to 1998, compared with larger numbers (30,493 for maize and 154,962 for wheat) by the US NPGS over a similar time period (1990–99). National collections in other richer countries provide another contrast. Two germplasm systems, the Nordic collection (representing the Scandinavian countries) and the Netherlands collection, have provided data that enable a comparison with US NPGS. Over the same 1990–99 period, the total of germplasm samples for all crops distributed to other countries by the Nordic collection was only 15,477, and for the Netherlands, 25,310. [2] These numbers represent but a fraction of total US NPGS distributions to other countries during the same period, based on only the 10 crops we have considered. Based on data reported by Shands and Stoner (1997), we estimate that these 10 crops account for slightly more than half the total distributions of all plant germplasm by US NPGS over the past decade.

The next section describes data sources used. Findings are reported in terms of three questions motivating the study, followed by estimates of actual use rates. Conclusions and implications are discussed in the final section.

3. DATA SOURCES

Data reported here are drawn from two sources. The first is data on germplasm distributed by US NPGS. The US National Germplasm Resources Laboratory, which manages the system's database (the Genetic Resources Information Network) and coordinates plant exploration and international exchange programs, provided quantitative information about samples distributed over 1990–99 for the 10 crops that we selected for study. The second source of information was original data that we collected directly from requestors of US NPGS germplasm. In order to implement this study, the US National Germplasm Resources Laboratory also supplied the names of all individuals who requested germplasm during 1995–99 for the 10 crops in question.

Because examining users of the entire US NPGS collection of 85 crops was not possible with the resources available to us, we focused on 10 crops. Five crops were selected based on their importance in world production: wheat, rice, soybeans (as a leading oil seed), maize (as the leading coarse grain) and barley (USDA, FAS, 2001). Cotton and sorghum are also leading crops in the United States, in terms of production volume, hence their inclusion. Potato, beans and squash were also included, not only because of their economic importance, but because they are indigenous to the Americas (as are maize and upland cotton).

To understand the nature of the demand for crop genetic resources conserved in gene banks, we need first to answer the fundamental questions of: (a) *who* uses the genebanks; (b) *what* kind of germplasm is used; and (c) *why* users want germplasm (for what purpose and in search of which plant characteristics) (Wright, 1997). We developed a study questionnaire around these questions.

Each requestor was sent a letter explaining the study and a form that asked for information about the recipient's experiences with US NPGS. The format by which responding users submitted information was intentionally brief, to ease response time and improve the response rate. The questionnaire was sent to international requestors for the first time in mid-2000. Users who did not respond to the first request were mailed a second request. Lists of respondents have remained confidential and are separated from data files.

A total of 1,063 individuals were included on the list of international requestors, though several names appeared more than once with different crops. Of these, 380 (36%) provided usable information. Response rates ranged from 23% to 45% by crop, with the lowest response rate in potato and the highest in wheat. For cotton, rice, sorghum and squash the number of responses was small for purposes of statistical analysis. The response rate was nearly twice as high in developed and transitional economies of the former Soviet Union and Eastern Europe as in developing countries, likely reflecting mail service difficulties.

Most of the international respondents had requested more than one seed sample. Since respondents reported the number of germplasm samples they received, we can analyze the information either by respondent or on the basis of germplasm samples. Both approaches are employed in this paper, depending on which is more appropriate for the analysis.

4. FINDINGS

(a) *Who requests germplasm?*

US NPGS in-house distribution data provide a clear picture of who uses public germplasm in the international community. The geographical pattern of distributions to other countries for the 10 crops is shown in Figure 1. According to US NPGS data, about a third of all samples were destined for countries in the Europe region, followed closely by other countries in the Americas (30%). Asia was the next largest regional recipient (23%), while the continent of Africa received only 13% of samples shipped. Geographical patterns reflect a number of factors, including the production zones of the crops in question, and the capacity of local scientists to utilize materials, which is, in turn, conditioned by their funding and the technologies available to them.

When classified by development status, developing countries as a group were distributed more germplasm (46%) than either developed countries or the transitional economies of Eastern Europe and the former Soviet Union (Figure 2). Together, developing and transitional countries received 63% of all germplasm samples sent to other countries during the past decade, or over 100,000 samples. Thus, internationally, this large national genebank is more likely to distribute public germplasm to recipients working in less technologically favorable conditions.

The distribution data also reveals some unexpected patterns with respect to the institutional affiliation of recipients (Table 1). First, as expected, the vast majority (77%) of germplasm samples sent outside the United States were distributed to noncommercial organizations. Second, the US national collections clearly supply more samples to public institutions concerned with crop breeding and research than to those dealing with conservation. Genebanks, especially international agricultural research centers, were less important recipients than crop improvement and research programs. Generally, private breeders are thought to rely primarily on their own collections (Mann, 1997; Wright, 1997), and their use of gene banks is believed to be limited—though in his survey of US breeders,

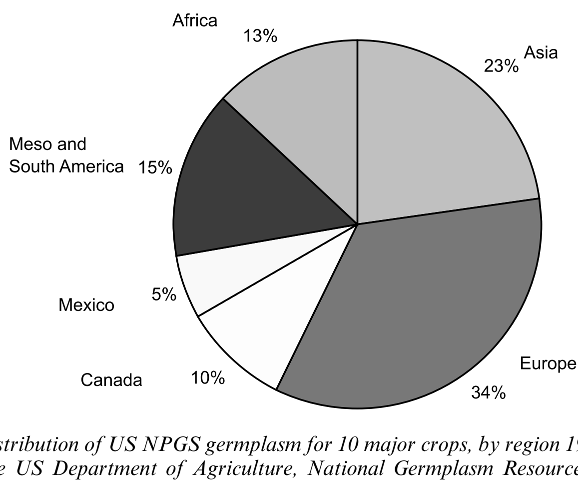

Figure 1. *International distribution of US NPGS germplasm for 10 major crops, by region 1990–99. Source: Calculated from data provided by the US Department of Agriculture, National Germplasm Resources Laboratory. Includes all germplasm samples distributed for barley, beans, cotton, maize, potato, rice, sorghum, squash, soybean, and wheat.*

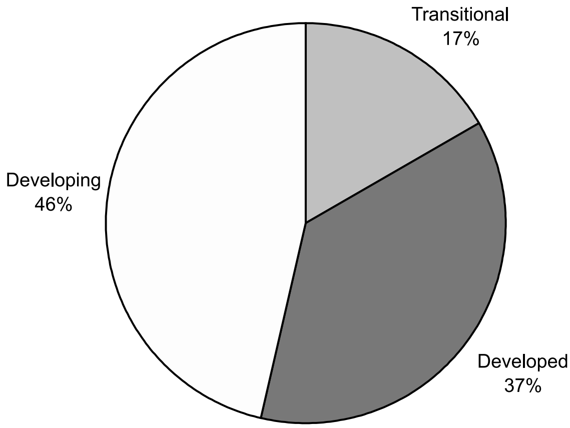

Figure 2. *International germplasm transfers from US NPGS for 10 major crops, by development status of receiving country, 1990–99. Source: Calculated from data provided by the US Department of Agriculture, National Germplasm Resources Laboratory. Includes all germplasm samples distributed for barley, beans, cotton, maize, potato, rice, sorghum, squash, soybean, and wheat.*

Table 1. *US NPGS germplasm distributions to other countries by type of receiving institution, 1990–99*[a]

Type of institution	Percentage of all samples distributed outside US
Commercial company	4.5
Genebank or genetic resource unit	12.8
Unaffiliated individual	0.6
Noncommercial organization	76.6
International agricultural research center	5.6
Total	100.0

Source: Calculated from data provided by the US Department of Agriculture, National Germplasm Resources Laboratory.
[a] Crops include barley, bean, cotton, maize, potato, rice, sorghum, soybean, squash, wheat.

Duvick (1984) found that private breeders make use of all germplasm sources. Indeed, only about 5% of the 167, 673 samples US NPGS sent abroad in the past decade were shipped to commercial requestors. Surprisingly, however, commercial companies receiving samples in other countries were twice as likely to be located in developing countries as in developed countries (Figure 3). Unaffiliated individuals were few, and most were found among the developed country recipients.

Among US NPGS users who participated in the study, a similar proportion were affiliated with governments, universities, or publicly funded research and development institutions (70%). A larger proportion of respondents (15%) worked for private seed, chemical or biotechnology companies or for privately funded research organizations than is represented in the data on total distributions for the decade. Since the average size of request was significantly greater for publicly funded than for private-funded institutions (Table 2), however, the proportional balance in terms of numbers of germplasm samples is similar between the two data sources.

(b) *What kind of germplasm is requested?*

Like other gene banks, the US NPGS supplies various types of germplasm to requestors. Materials are categorized as: (i) elite or modern, (ii) landraces, (iii) wild and weedy relatives, and (iv) genetic stocks. [3] The first category includes all materials improved by professional plant breeders. This material can be broken into two categories, the first being "cultivars," which includes recently developed cultivars, and "obsolete" cultivars that are no longer grown. The second kind of elite modern germplasm is advanced breeding material, which includes the advanced lines that breeders combine to produce new cultivars (sometimes referred to as "breeding materials"). Landraces, or traditional varieties, are varieties of crops that were improved by farmers over many generations without the use of modern breeding techniques. Wild or weedy relatives are plants

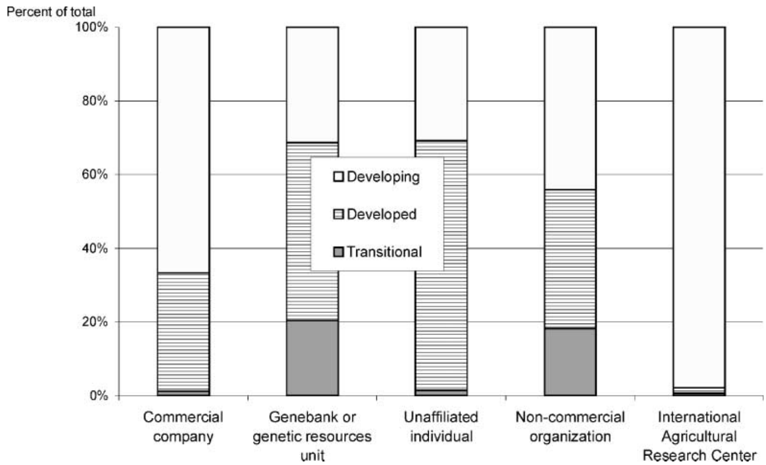

Figure 3. *Distribution of germplasm samples sent from US NPGS to other countries from 1990–99, by development status of recipient's country. Source: Calculated from data provided by the US Department of Agriculture, National Germplasm Resources Laboratory. Includes all germplasm samples distributed for barley, beans, cotton, maize, potato, rice, sorghum, squash, soybean, and wheat.*

that share a common ancestry with a crop species but have not been domesticated. Germplasm collections may also include "genetic stocks." Genetic stocks are mutants or other germplasm with chromosomal abnormalities that may be used by plant breeders for specific purposes.

Different germplasm types serve different breeding objectives. Landraces and wild relatives are often used for resistance traits, and generally require extensive efforts before their genes are usable in a final variety. A survey of international users of wheat germplasm suggested that only a minor percentage of materials used in crossing were landraces or wild relatives, and these were more likely to be used in search of resistance traits than for yield potential. Wheat breeders working in developing countries also used them in breeding for grain quality more often than those working in developed countries (Rejesus, Smale, & Van Ginkel, 1996). Demand for advanced breeding material implies an active breeding program. Genetic stocks are often used for highly sophisticated breeding, and also for basic research. While the use of cultivars may suggest that instead of breeding, researchers are "fishing" for useful final varieties, cultivars may also serve breeders when they are looking for specific traits. Drawing conclusions from requests for cultivars is therefore difficult.

Table 2. *Average number of germplasm samples requested from US NPGS by international respondents, by institution type*[a]

Type of institution	Average number of germplasm samples requested per respondent[b]
Private companies or private R&D	57
Government, university, or public R&D	153[c]
National, regional, or international genebank	214[c]
Self-employed, seed savers, or NGOs	30
All respondents	119

Source: Study conducted by International Plant Genetic Resources Institute.

[a] Total number of respondents = 380.

[b] Requests (rows) sum to more than 100% when requests of more than one material type are made.

[c] Pairwise *t*-tests show significantly (0.01) greater average sizes of request for genebanks and publicly funded institutions relative to other groups.

Roughly half of all respondents to the international study requested cultivars, and an equal number requested landraces or wild relatives—suggesting a unexpected demand for exotic materials. Genetic stocks were requested by slightly more than 27% of respondents, while advanced materials were requested by about 21% of all respondents (Table 3). [4]

Demand for germplasm types also depends on the breeding needs for the crop in question. Landraces and wild relatives were most at-

Table 3. *Germplasm types requested from US NPGS by international respondents, by crop*[a]

Crop	Percentage of respondents requesting germplasm type			
	Cultivar[b]	Advanced material	Genetic stocks[b]	Landraces or wild relatives[b]
Barley	59	18	15	54
Beans	50	22	15	65
Maize	20	26	49	30
Potato	31	9	28	75
Soybeans	77	23	35	33
Wheat	60	22	15	56
All crops surveyed	49	21	27	48

Source: Study conducted by International Plant Genetic Resources Institute.

[a] Total number of respondents = 380. Cotton, rice, sorghum, and squash excluded here because of small subsample sizes. Requests (rows) sum to more than 100% when requests of more than one material type are made.

[b] Pearson chi-squared tests (two tails, significance level = 0.01) show significant differences in percent requesting material type by crop.

Table 4. *International requests for US NPGS germplasm types, by development status of respondent's country*[a]

Development status	Percentage of respondents requesting germplasm type			
	Cultivar	Advanced material[b]	Genetic stocks	Landraces or wild relatives[b]
Developed countries	46	16	24	53
Developing countries	51	22	36	33
Transitional economies	59	26	22	48
All	49	21	27	48

Source: Study conducted by International Plant Genetic Resources Institute.

[a] Total number of respondents = 380. Requests (rows) sum to more than 100% when requests of more than one material type are made.

[b] Pearson chi-squared tests (two tails, significance level = 0.01) show significant differences in percent requesting material type by development status.

tractive to respondents working with potatoes, a crop with an extremely narrow genetic base, and for which breeders need to broaden the germplasm used to realize any significant improvements (Haynes, 2001). Though soybean also has a narrow genetic base in most countries except China, Japan, and Korea, cultivars were more likely to be demanded for this crop than for others.

Genetic stocks were most likely to have been requested by respondents asking for maize accessions, and dominated maize requests relative to other types of materials. The greater level of basic research concerned with maize, combined with features of maize seed industry structure, may help to explain the greater demand for genetic stocks by maize researchers relative to other germplasm types and compared with that of scientists working with other crops. Virtually all of the maize area in the developed world is planted to hybrid seed that is bred, multiplied and sold by private companies (Echeverria, 1991). The same is true in developing countries where maize is commercially grown (Lopez-Pereira & Filippello, 1994), though maize seed industries there are highly variable in organization and performance (Morris, 1998). In many cases, basic research in maize is conducted by public institutions rather than by private firms. Since private firms dominate maize seed research, an institution such as US NPGS may represent the primary source of materials for publicly employed scientists in other countries who are conducting basic research. Another factor explaining the relative low percentages of requests for cultivars, landraces and wild relatives in maize cultivars is the difficulty of combining tropical and temperate germplasm because of their dramatically different photoperiodic responses (Goodman, 1995). A comprehensive survey conducted in 1983 on the use of exotic germplasm in commercial maize revealed that less than 1% of the US germplasm base consisted of exotic germplasm (Goodman, 1985). At the same time, the vast majority of the improved maize materials developed for use in the United States, Western Europe, and northern China are of little direct use to maize farmers in developing countries (Morris, 1998, p. 15). Though the findings in Table 3 should be interpreted with caution, a sum of row percentages further suggests that scientists requesting maize accessions tended to focus on fewer germplasm types than did those asking for samples of other crops.

The type of germplasm demanded differed significantly by the development status of the country. Respondents from developed countries were less likely to request advanced materials than those in developing and transitional economies. Respondents from developing countries requested landraces and wild relatives less frequently than did respondents from developed and transitional countries (Table 4). These results suggest that requestors in developing countries sought materials that could be incorporated more immediately into breeding programs, whereas those from developed countries were interested in rarer traits or materials suitable for basic research. It is also possible that when landraces are used by developing country scientists in breeding for resistance or grain quality, they are more likely to look first among the local landraces that are still grown by their country's farmers, when available, than to distant gene bank collections.

(c) *Why is germplasm requested?*

(i) *Purpose of request*

Breeders are always seeking an improvement on the status quo. They look for germplasm with certain characteristics, such as better resistance to a pest, or higher yield. Study respondents reported four categories of intended use for germplasm they requested: trait evaluation, breeding or prebreeding, basic research, and adding to collections. Since samples could be intended for multiple purposes, percentages across purposes may total to more than one hundred.

Samples were most likely to be intended for trait evaluation (55% of samples). Evaluation for specific traits indicates an active breeding program in which scientist do not simply test existing varieties, but work to develop new varieties. Providing material internationally for basic research (36% of samples) also appears to be an important function of the US NPGS, though that role generally receives little attention. Twenty-five percent of samples were to be added to collections, and 23% were for breeding and prebreeding. Combined, breeding/prebreeding and evaluation for traits (essentially a subset of breeding/prebreeding) account for 78% of the intended use of samples. This reiterates the idea that genebanks supply most of germplasm samples to institutions concerned with breeding, followed by research institutions, and then other germplasm collections.

Respondents in developed, developing, and transitional economies varied somewhat in how they intended to use germplasm. Consistent with our other findings, on average, respondents in developed countries intended a higher proportion of their shipments to be used in basic research, reflecting, perhaps, their technological advantages. Respondents in transitional economies allocated a higher percentage to collections.

(ii) *Traits sought*

The nature of the traits sought provides further insight into scientists' demand for germplasm held in genebanks. International respondents were asked to classify the traits they sought into five categories: tolerance to abiotic stresses, tolerance or resistance to biotic stresses, yield, quality or other. Tolerance to abiotic stress includes drought tolerance, salinity tolerance, and temperature tolerance. Biotic stresses are usually pests, including diseases, which attack plants. Yield, in the pure sense, means an increase in a plants productive capacity, assuming ideal growing conditions. Quality generally means some characteristic of the final agricultural product, such as the gluten content of wheat, or the oil content of maize.

Respondents generally intended to use a higher proportion of samples they requested for biotic resistance or tolerance than for other traits, regardless of the improvement status of the material (Table 5). Since samples may be used to search for more than one trait, totals

Table 5. *Traits sought by international respondents, by sample germplasm type*[a]

Material	Average percent of samples used to search for trait				
	Abiotic tolerance	Biotic resistance or tolerance	Yield[b]	Quality[b]	Other
Cultivars	17	37	17	22	25
Advanced breeding material	14	44	25	24	20
Landraces	13	35	12	24	27
Wild relatives	13	42	3	14	31
Genetic stocks	12	24	6	11	44
All materials	14	37	13	19	29

Source: Study conducted by International Plant Genetic Resources Institute.

[a] Total number of respondents = 380. Row totals may exceed 100% if accessions are used to search for more than one trait.

[b] Pairwise *t*-tests (two tails, significance level = 0.05) show significant differences by germplasm type in average percent of samples requested to search for yield and quality.

may exceed 100% for each germplasm type. Thirty-seven percent of germplasm samples were used to search for resistance or tolerances of biotic stresses. This finding was expected, since resistance to pests, including diseases, is thought to be a primary motivation for breeding (Duvick, 1992). Quality traits were the desired characteristic in 19% of the germplasm. Abiotic resistance was sought for about 14% of the germplasm, respectively. A lower proportion of germplasm samples (13%) was intended for advancing yield potential. Because many increases in on-farm yield actually come from improvements in resistance, the relatively lower percentage of samples used to seeking yield advances is not surprising. The average percent of requestors intended to use samples for specific "other uses" was also relatively high. When explanations for other uses were examined, most fell into the category of basic research, such as genomics.

The average percentage of samples intended for yield or quality advances varied significantly according to the sample germplasm type. On average, respondents intended to use advanced breeding materials for yield potential significantly more frequently than landraces or wild relatives. In addition to advanced materials, a higher percentage of landraces were requested in pursuit of quality traits than were wild relatives. Genetic stocks seem to have been intended primarily for the "other" traits of interest; particularly those connected to basic research.

(d) *Actual utilization of germplasm samples*

In assessing the use of US NPGS germplasm, we note that the long-term nature of plant breeding and agricultural research, combined with the reproducible nature of seed, implies that utilization rates calculated over a short period of time underestimate actual use patterns in both temporal and spatial terms. That is, materials may be useful much later in a breeding cycle than when they are first received, and they may be incorporated into research multiple times by different users.

Even so, respondents' perceptions about the usefulness of the samples that they received are a good indicator of the actual utilization of US NPGS germplasm samples in international breeding programs. Within the brief 5-year period covered by the respondents, 11% of germplasm accessions had already been incorporated into a breeding program (Table 6). Given the long time period required to breed a new variety, it is not surprising that much of the material is still being evaluated, and it is encouraging that 43% of the samples were deemed worthy of further investigation. Respondents considered 18% of the samples useful in other ways, leaving only 28% of samples not useful at all. Overall, an estimated 72% of materials sent from US NPGS to other countries has already been used in breeding, considered worthy of further assessment, or found otherwise useful.

If we apply the percentages obtained from study responses to the total numbers of germplasm samples distributed during 1995–99, we generate an estimate of the actual numbers of germplasm samples used during that period for the 10 crops considered. Our findings suggest that, in other countries alone, over 18,000 germplasm samples from US NPGS have already been used in breeding and in other ways, while another 27,000 are still under evaluation.

Table 6. *Estimated utilization of germplasm samples sent to international requestors by US NPGS, 1995–99, by development status of recipient's country*[a]

Material type	Used in breeding program		Still being evaluated		Useful in other ways		Not useful		Total %	Total samples distributed
	Survey %	Estimated total 1995–99	Survey %	Estimated total 1995–99	Survey %	Estimated total 1995–99	Survey %	Estimated total 1995–99		
Developed	5	959	39	8,213	31	6,421	26	5,451	100	21,045
Developing	16	5,242	52	16,879	10	3,151	21	6,880	100	32,151
Transitional	6	623	22	2,330	19	1,972	52	5,434	100	10,359
All recipients	11	6,824	43	27,422	18	11,544	28	17,765	100	63,555

Source: Study conducted by International Plant Genetic Resources Institute.

[a] Total number of respondents = 380. Study estimates are applied to actual distributions data provided by the National Germplasm Resources Laboratory.

Table 7. *US NPGS samples shared by international respondents with others, 1995–99, by development status of respondent's country*[a]

Development status	Seed samples shared with others			
	At own institution		At another institution	
	Survey %	Estimated total 1995–99	Survey %	Estimated total 1995–99
Developed	14	2,891	3	626
Developing	23	7,496	16	5,055
Transitional	13	1,329	4	442
All countries	18	11,715	10	6,123

Source: Study conducted by International Plant Genetic Resources Institute.
[a] Total number of respondents equals 380. Study estimates are applied to actual distributions data provided by the National Germplasm Resources Laboratory, US Department of Agriculture.

This is an impressive finding. Of course, it is important to remember that users in developed countries made up a smaller percentage of the study respondents than they did of the total recipients, and researchers working in the private sector were more heavily represented in the study than in the total distributions data. We have no indication however of whether this difference in representation would bias findings, and the overall response rate was good for mailed questionnaires.

Developing country respondents reported that 16% of the germplasm samples they received were already put to use in breeding programs—about three times the percentage reported by respondents in developed and transitional economies (Table 6). In fact, scientists working in developing countries found nearly 80% of the samples useful or worthy of further study. Those working in transitional countries found half their samples "not useful;" at least twice the percentage of samples characterized as such by developing and developed countries. Larger numbers of germplasm samples are "useful in other ways" for developed country recipients. While the exact use of such germplasm is unclear, it may reflect the higher levels of the basic research associated with developed economies.

Germplasm can be distributed by the original recipient to additional users, generating secondary benefits. Respondents shared 18% of all germplasm samples with other scientists at their own institution and 10% with those in other institutions. These secondary transfers are of a larger magnitude for developing country respondents than for respondents in developed and transitional economies (Table 7). Again, applying the findings from the user study to the total number of samples distributed, our estimates suggest that secondary transfers may represent an additional utilization of as many as 17,500 samples.

One factor affecting the usefulness of germplasm is the presence of data. Accessions may have data that can generate value by speeding the research discovery process. For all 10 crops, respondents reported that 28% of samples had useful data for the trait of interest and 18% had useful data for other purposes (Table 8). The percentage of samples with useful data for the trait of interest was slightly higher among developing country respondents (31%). The total samples with useful data for the trait of interest was therefore substantially larger for developing country recipients compared with developed country recipients. Developed country respondents, on the other hand, found that a greater percentage of samples had useful data for other purposes, which would include basic research.

(e) *Future demand*

International respondents' expectations regarding utilization of US NPGS germplasm in the next decade provided some indication of future demand for public germplasm. There were no significant differences by crop or institution type in the percentages of respondents expecting to increase, decrease, or maintain their utilization. Again, however, there were statistically significant differences by the development status of the respondent's country. A majority of respondents in developing countries expected to increase their requests from US NPGS in the next decade, and they were more likely to respond positively than those from

Table 8. *US NPGS samples with useful data, sent to international respondents 1995–99, by development status of requestor's country*[a]

Development status	Seed samples with useful data			
	For trait of interest		For other purposes	
	Survey %	Estimated total 1995–99	Survey %	Estimated total 1995–99
Developed	27	5,619	25	5,358
Developing	30	9,750	13	4,327
Transitional	21	2,173	14	1,499
All countries	28	17,541	18	11,184

Source: Study conducted by International Plant Genetic Resources Institute.

[a] Total number of respondents equals 380. Study estimates are applied to actual distributions data provided by the National Germplasm Resources Laboratory, US Department of Agriculture.

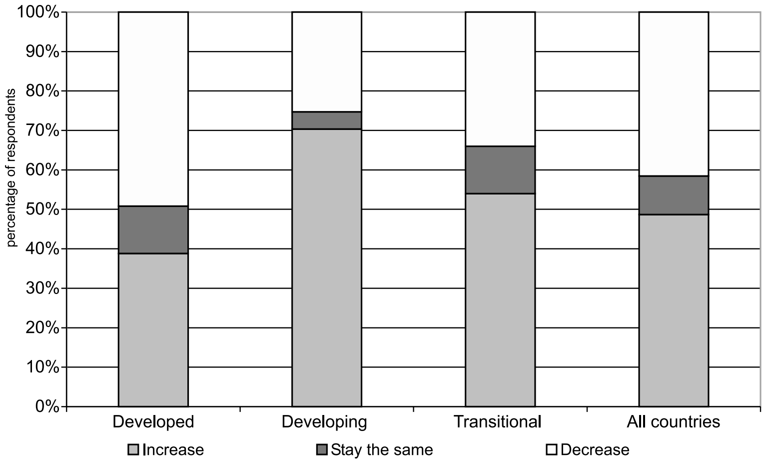

Figure 4. *International respondents' expectations for US NPGS germplasm use over the next decade, by development status of country and institutional affiliation. Source: Study conducted by International Plant Genetic Resources Institute. Pearson chi-squared tests (two tails, significance* level = 0.01*) show significant differences in percentages by development status.*

either developed or transitional economies (Figure 4).

(f) *Problems to solve*

Respondents were given the opportunity to state any additional perceptions about the benefits and problems of the US NPGS. While positive statements about the benefits of the US NPGS outweighed comments about problems by approximately three to one (Table 9), some important limitations were expressed.[5] The most common problem, by far, was inadequate or incomplete information about germplasm samples, accounting for 38% of all problems cited. Still, positive comments about data/information as a benefit slightly outweighed comments about data/information as a problem. Interestingly, the second most commonly mentioned problem was regulations that affect germplasm exchange. Quarantine restrictions, particularly in the European Union, seemed to cause concern among some of these respondents. This may account, at least in part, for the fact that relatively more respondents in developed countries, expected their use of US NPGS germplasm to decline in the next decade. Another US NPGS-specific problem was seed quality concerns, e.g., seeds that were not viable, or which were contaminated. This was the third most frequently cited problem. Insufficient funding for maintaining seed viability, as well as inadequate resources for data assessing the US NPGS accessions was reported by a

Table 9. *Perceived benefits and problems of using US NPGS, international respondents*[a]

Perceptions	Frequency	Percentage of responses in category	Percentage of all responses percent
Benefits			
General			
Seed or materials	88	24	18
Good data or information	48	13	10
Acquisition and collection	14	4	3
Characterization and evaluation	11	3	2
Enhancement and cultivar development	2	1	0
Preservation, conservation, maintenance	48	13	10
Distribution	78	22	16
US NPGS-specific attributes[b]	73	20	15
Subtotal	362	100	76
Problems			
General			
Inadequate resources	12	10	3
Material useful only after prebreeding	1	1	0
Regulations inhibiting germplasm exchange	17	15	4
Private sector unwilling to contribute	4	3	1
Need more in situ conservation	2	2	0
NPGS-specific attributes	15	13	3
Seed did not germinate, samples impure			
Information incorrect, incomplete, not useful	45	38	9
Some germplasm under-represented	4	3	1
Distribution problems	12	10	3
Communication	5	4	1
Subtotal	117	100	24
All responses	479		100

Source: Study conducted by International Plant Genetic Resources Institute.

[a] Total number of respondents equals 380.

[b] Category includes size and completeness of collection, reliability, web access, ease of access, etc.

GAO study (USGAO, 1997). Finally, the fourth-ranking problem was inadequate funding/resources, a factor, like regulation, outside the control of the US NPGS, but one that may lay at the root of data and seed viability problems.

5. CONCLUSIONS

The study findings demonstrate that US NPGS plays an important role in providing public germplasm to developing countries. The total number of samples distributed during 1990–99 among the 10 crops we studied favors developing countries as a group relative to either the transitional economies of the Former Soviet Union and Eastern Europe or developed economies. At least in terms of the relative scarcity of technologies and small sizes of public research budgets in developing countries (as compared to developed countries), it is likely that the relative marginal economic value of these resources to these countries is also higher.

In their earlier study, Shands and Stoner (1997) suggested that requests from nonindustrialized countries were constrained, in part, by the lack of adaptation of US NPGS germplasm to certain environments, and in part by the lack of capacity and support in many of these countries for crop improvement programs. Their first conclusion is drawn from their own examination of the geographical pattern of germplasm distributions. The data presented here are consistent with their second conclusion, to some extent. Respondents from developing countries intended to use a lower average proportion of the materials received for basic research than did scientists in developed countries, while more were requested for breeding purposes, trait evaluation, and adding to collections in the developing world. But the higher percentage of respondents from developing countries requesting advanced materials suggests active breeding programs.

Furthermore, utilization rates in breeding, as reported by respondents during 1995–99 period, are much higher among developing country respondents than those in developed countries. Larger numbers of germplasm samples are still being evaluated, while fewer samples have been shown to be "useful in other ways." Developing country respondents tended to share materials more often with other researchers in their own institution and elsewhere. Finally, respondents from developing countries expect to increase their use of the US NPGS over the next decade, while those in developed countries were less optimistic (again, perhaps due to restrictions on germplasm exchange). Our findings indicate developing countries' reliance on the US NPGS is greater than that of developed countries, and that their benefits may exceed those of other countries, at least insofar as direct utilization in breeding programs is concerned.

A second major conclusion concerns the meaning of the term "use." In contrast to the perception that *ex situ* collections of crop genetic resources are rarely used, our study suggests that national genebanks such as the US NPGS generate multiple, global benefits to users. First, the numbers of germplasm samples distributed are large—and we have accounted for only 10 crops, or approximately half of total distributions over a single 10-year period. The volume of transfers to other countries compares favorably with transfers by other national collections in developed countries and those held at international agricultural research centers.

Multiple benefits are suggested by the extent of utilization by respondents, the breadth of materials they requested, and the range of institutions served. With respect to utilization, respondents stated that 11% of the samples received internationally during the last 5 years have already been incorporated into breeding programs, while another 43% are still being evaluated and 19% have been useful in other ways. In addition to the germplasm itself, accompanying data also had benefits in use either for the trait of interest or some "other purpose." In terms of materials, though almost half the respondents requested cultivars, nearly as many respondents requested landraces, demonstrating a demand for exotic germplasm. Genetic stocks and advanced materials were also requested by a substantial proportion of respondents, indicating good demand for these types of germplasm that is likely to derive from fairly sophisticated breeding/research programs. This national gene bank also serves a variety of institutions, of which the majority are publicly funded research organizations, though private companies are also represented. The findings presented here demonstrate in simple, unequivocal terms the magnitude and breadth of the benefits generated by the US NPGS collection.

6. IMPLICATIONS

Our third and final conclusion is that the benefits this national genebank likely generates for developing countries should not be underestimated in the current negotiations over future access to publicly held crop genetic resources. According to respondents, regulations concerning seed exchange are a primary external problem the US NPGS faces. While the problems associated with inadequate resources are easily perceived, the role of germplasm exchange regulations is subtler. Like funding constraints, however, regulations affect the operations of the collections in fundamental ways.

Since the UN Food and Agriculture Organization (FAO) established the Commission on Plant Genetic Resources in 1983 (as it was then called), countries have sought to reach international agreement on access to genetic resources and the distribution of the benefits they create. FAO Conference 9/83 established the International Undertaking on Plant Genetic Resources for Food and Agriculture. Acceptance of the Undertaking has not been universal, and the debate has been complicated by efforts to bring the Undertaking into harmony with the Conventional on Biological Diversity. [6] The Convention grants countries sovereign rights over their genetic resources, a change from the traditional "free flow" of what used to be classified as "unimproved" genetic resources and landraces. Sovereign rights are intended to improve the ability of resource holders to collect some of the benefits of their genetic materials, thus increasing incentives for conservation. The exact provisions for access to resources and the sharing of their benefits have been highly contentious (IISD, 2001), with much of the debate falling historically along

North–South (i.e., developed country–developing country) lines (Kloppenburg, 1988). While the new International Treaty on Plant Genetic Resources for Food and Agriculture appeared to have settled some of the debates, the Treaty is ambiguous or vague on several important issues. Among them is the role of nonparties in germplasm exchange with the Multilateral System. Because the United States is not a party to the International Treaty, the ability of the US NPGS to access needed germplasm is unclear.

Many developing countries are considered "germplasm rich," that is they include or are near centers of domestication. In the past, these countries often supplied genetic resources free of charge, particularly to "germplasm-deficient" developed countries where they were used to create modern varieties sold commercially. Such genetic resources included landraces that resulted from generations of effort from farmers who selected and conserved germplasm. Both the Undertaking and the Convention have raised hopes that countries with germplasm needed by breeders could establish "farmers' rights" to much of this germplasm (Cooper, 1993). This would allow these countries to collect the some of the benefits arising from such farmer-led efforts, as well as benefits from other genetic resources held. Provisions for farmers' rights are included in the International Treaty, but again, are vague. Likewise, the financial provisions of the Treaty are relatively vague on the sources of funding. Some is expected to come from the commercialization of plant genetic resources that flow through the system: recipients commercializing products that contain germplasm from the Multilateral System shall pay an "equitable share" of benefits gained (International Treaty, 2001, Article 13.2d). But determining the equitable share of the percentage of returns attributable to particular germplasm is a thorny problem, as is the enforcement of such a provision.

The implications of our research for such agreements are complex. Our results suggest a healthy demand for all types of germplasm. Countries with genetic resources useful for agriculture may see this as reason to hope that their resources could be marketed and financial returns received, either directly from nonparties or as a percentage of returns from commercial products. But, much of the publicly held germplasm flows to researchers within the public system, where commercial products are not likely to be among their primary outputs. Because the US NPGS provides germplasm free of cost and without "reach through" rights for commercialized products, demand for its germplasm does not necessarily indicate a "willingness to pay" for similar resources. Moreover, because much of the demand came from developing countries, such users of agricultural germplasm may not have the financial resources to generate substantial returns for resource holders. In terms of directly marketed germplasm, "free" germplasm from places such as US NPGS and international genebanks would likely be a desirable substitute. The US NPGS itself can be seen as a potential buyer of unique germplasm not already in its collections. Like genebanks throughout the world, however, the US NPGS faces serious budget constraints, as stated earlier. It is doubtful that it would be able to produce significant funds for such acquisitions. Such financial constraints have also impeded the collection of funds through the public sector as part of the process to compensate farmers' rights. Thus, we conclude that national genebanks probably will not be good sources for compensation funds, and efforts to collect such funds may want to focus on other potential sources.

The clearest conclusion suggested by this study is that, though maintaining public access to the resources housed in the US NPGS serves its national scientists, the international scientific community also benefits greatly. The role played by this bank is complementary to that of the international collections in magnitude and direction, offsetting the view that developed countries continues to benefit disproportionately from the utilization of genetic resources that originated within the national boundaries of today's developing countries.

NOTES

1. According to the National Research Council (1993, p. 407), an accession is a distinct, uniquely identified sample of seeds, plants, or other germplasm materials that is maintained as an integral part of a germplasm collection. Many seed samples may be distributed for the same accession, to different requestors.

2. Data reported to the Global Forum for Agricultural Research (GFAR).

3. Another category of germplasm is "unknown." Such undefined germplasm samples were not included in these calculations.

4. Because respondents could request more than one type of germplasm, numbers sum to more than 100%.

5. Each response was classified into one of eight main categories (based on the judgment of the authors). Those respondents who made comments often offered more than one. In those cases, each comment was considered individually.

6. In addition to the Undertaking and the Convention, we wish to note the Uruguay Round of the General Agreement on Trade and Tariffs (GATT) of 1986. While discussion of it is beyond the scope of this paper, one important component of the GATT is settlement of trade related aspects of intellectual property rights. The GATT creates minimum standards for the protection of intellectual property rights over commercially developed seed and plant varieties, and through that, has moved closer to more universal recognition of plant breeders' rights.

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APPENDIX

LIST OF 237 COUNTRIES, TERRITORIES, DEPARTMENTS, OR COMMONWEALTH ASSOCIATIONS TO WHICH US NPGS DISTRIBUTED GERMPLASM SAMPLES FROM 1990–99

Afghanistan	Djibouti	Liberia	Saint Kitts and Nevis
Albania	Dominica	Libyan Arab Jamahiriya	Saint Lucia
Algeria	Dominican Republic	Liechtenstein	Saint Pierre and Miquelon
American Samoa	East Timor	Lithuania	Saint Vincent and the Grenadines
Andorra	Ecuador	Luxemburg	Samoa
Angola	Egypt	Macau	San Marino
Anguilla	El Salvador	Macedonia	São Tome e Principe
Antigua and Barbuda	Equatorial Guinea	Madagascar	Saudi Arabia
Argentina	Eritrea	Malawi	Senegal
Armenia	Estonia	Malaysia	Serbia
Aruba	Ethiopia	Maldives	Seychelles
Australia	Falkland Islands (Malvinas)	Mali	Sierra Leone
Austria	Faroe Islands	Malta	Singapore
Azerbaijan	Fiji	Marshall Islands	Slovenia
Bahamas	Finland	Martinique	Solomon Islands
Bahrain	France	Mauritania	Somalia
Bangladesh	French Guiana	Mauritius	South Africa
Barbados	French Polynesia	Mexico	Spain
Belarus	French Southern Territories	Micronesia	Sri Lanka
Belgium	Gabon	Moldova, Republic of	Sudan
Belize	Gambia	Monaco	Surinam
Benin	Georgia	Mongolia	Svalbard and Jan Mayen Islands
Bermuda	Germany	Montserrat	Swaziland
Bhutan	Ghana	Morocco	Sweden
Bolivia	Gibraltar	Mozambique	Switzerland
Bosnia and Herzegovina	Greece	Myanmar	Syrian Arab Republic
Botswana	Greenland	Namibia	Taiwan, Province of China
Bouvet Island	Grenada	Nauru	Tajikistan
Brazil	Guadeloupe	Nepal	Tanzania
British Indian Ocean Territory	Guam	Netherlands	Thailand
British Virgin Islands	Guatemala	Netherlands Antilles	Togo
Brunei	Guinea	New Caledonia	Tokelau
Bulgaria	Guinea-Bissau	New Zealand	Tonga
Burkina Faso	Guyana	Nicaragua	Trinidad and Tobago
Burundi	Haiti	Niger	Tunisia

Cambodia	Heard and Mc Donald Islands	Nigeria	Turkey
Cameroon	Honduras	Niue	Turkmenistan
Canada	Hong Kong	Norfolk Island	Turks and Caicos Islands
Cape Verde	Hungary	Northern Mariana Islands	Tuvalu
Cayman Islands	Iceland	Norway	Uganda
Central African Republic	India	Oman	Ukraine
Chad	Indonesia	Pakistan	United Arab Emirates
Chile	Iran	Palau	United Kingdom
China	Iraq	Palestine	United States Misc. Pacific Islands
Christmas Island (Australia)	Ireland	Panama	United States of America
Cocos (Keeling) Islands	Israel	Papua New Guinea	Uruguay
Colombia	Italy	Paraguay	Uzbekistan
Comoros	Jamaica	Peru	Vanuatu
Congo	Japan	Philippines	Vatican City State
Congo, Dem. Rep. of the	Jordan	Pitcairn Islands	Venezuela
Cook Islands	Kazakhstan	Poland	Viet Nam
Costa Rica	Kenya	Portugal	Virgin Islands (US)
Côte d'Ivoire	Kiribati	Puerto Rico	Wallis and Fortuna Islands
Croatia	Korea, Republic of	Qatar	Western Sahara
Cuba	Kuwait	Reunion	Yemen, Republic of
Cyprus	Kyrgyzstan	Romania	Yugoslavia
Czechoslovakia	Lao People's Democratic Republic	Russian Federation	Zaire
Dem. People's Rep. of Korea	Latvia	Rwanda	Zambia
Denmark	Lebanon Lesotho	Saint Helena	Zimbabwe